A laboratory comparison of three imaging systems for image quality and radiation exposure characteristics

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Abstract

Bhaskaran V, Qualtrough AJE, Rushton VE, Worthington HV, Horner K. A laboratory comparison of three imaging systems for image quality and radiation exposure characteristics. *International Endodontic Journal*, **38**, 645–652, 2005.

Aim To measure and compare the relationships between image quality and X-ray exposure for three types of intraoral imaging system (conventional film, phosphor plate system and CCD-based system).

Methodology Kodak 'Insight' F-speed film, Digora FMX (phosphor plate system) and Visualix USB (CCD system) were used to produce series of radiographic images of two tooth-bearing jaw specimens (maxillary molar and mandibular molar regions) at a range of X-ray exposures from 10 ms to 2000 ms (all at 6 mA and 60 kV). Digital images were viewed from a computer monitor and films viewed on a conventional light box. Five observers scored each image using a five-point subjective image quality scale (0–4).

Results Optimum image quality (4) was seen for conventional film. Neither digital system achieved this score at any exposure, achieving in both cases a maximum mean score of 3.1 (adequate visualization). The two digital systems, however, provided adequate visualization at substantially lower exposure times. Dose reduction over conventional film for maximum quality images with Visualix USB was 20%, but for Digora FMX it was 70%. All three systems gave acceptable (quality score of two or higher) images over a broad range of exposures.

Conclusions In terms of subjective image quality, F-speed film performed better than the two digital systems, but this must be weighed against the ability of the two digital systems to give adequate image quality at lower radiation doses.

Keywords: dental, digital, endodontics, radiography, root canal therapy.

Received 14 February 2005; accepted 26 April 2005

Introduction

Imaging plays a key role at all stages of root canal treatment, from initial diagnosis through to post-treatment review. The clinician, using X-ray images to evaluate physically small structures such as root canals and the periodontal ligament, requires excellent image detail. Principally because of the development of digital radiography, but also as traditional film technology evolves, the clinician is faced with greater choice of imaging systems. This choice is influenced by nonclinical factors such as cost and availability of technical support, but image quality and radiation exposure are the paramount clinical considerations.

Two main types of intraoral digital X-ray systems are currently marketed, those based on the phosphor plate technology familiar to medical radiologists and those that use CCDs within the sensor. New systems and updated versions of existing systems regularly appear. Despite this, conventional film continues to be developed, with F-speed film now in general use. These changes in imaging technologies mean that there is a continual need to update the literature on the relative imaging performance of different systems. Previous work assessing digital imaging systems for endodontic

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purposes has tended to focus upon specific technical tasks such as working length estimation and root canal visibility (Shearer *et al.* 1990, 1991, Sanderink *et al.* 1994, Ellingsen *et al.* 1995, Ong & Pitt-Ford 1995, Velders *et al.* 1996, Barbat & Messer 1998, Cederberg *et al.* 1998, Burger *et al.* 1999, Eikenburg & Vandre 2000, Shearer *et al.* 2001, Friedlander *et al.* 2002, Lozano *et al.* 2002, Mentes & Gencoglu 2002). A few studies have considered the influence of exposure time on image quality (Borg & Grondahl 1996, Lim *et al.* 1996, Borg *et al.* 2000, Kitagawa *et al.* 2000, Berkhout *et al.* 2004), but none of these have specifically considered only those structures of particular importance to endodontists (endodontic files, root canal anatomy, periodontal ligament space, lamina dura and periapical bone detail).

The aim of this study was, therefore, to measure and compare the relationships between image quality and X-ray exposure for three types of intraoral imaging system (conventional film, phosphor plate system and CCD-based system).

Materials and methods

Bone material

A human maxilla and mandible were selected from a collection in the University Dental Hospital of Manchester on the basis that they were structurally sound and had one or more teeth present and in contact. Maxillary left first and second molar (26 and 27) and mandibular left first molar (36 and 37) regions were selected for specific interest in the study. These two regions and associated teeth are hereafter referred to as Region 1 (maxilla) and Region 2 (mandible), respectively.

Teeth 26, 27, 36 and 37 each had endodontic access cavities prepared using conventional techniques. Selected canals were identified and shaped coronally to facilitate instrumentation. These canals were irrigated repeatedly using 0.5% sodium hypochlorite solution followed by drying with paper points.

Size 10 and 15 Hedstroem files were placed in the selected canals (Table 1) and positioned at the apical constrictions, while other canals were left empty. The files were fixed *in situ* using Vitremer Core build up material (3 M Dental products, St Paul, MN, USA). After sealing, the protruding parts of the files were sectioned with a diamond cutting disc to leave the occlusal surface smooth.

In order to mimic overlying soft tissues of the cheek, an equivalent material was required that could be adapted to the bone and teeth. Preliminary simple radiographic comparison of green stick impression compound (Kerr Ltd, Peterborough, UK) showed that it had attenuation properties approximately twice that of acrylic (a commonly used soft tissue equivalent used in radiographic studies). Consequently, a layer of approximately 5 mm of impression compound was adapted to the buccal surfaces of teeth and bone.

Table 1 The teeth selected for use in the study with details of the canals present and their status as regards presence or absence of an endodontic file. '10' and '15' refer to file size. 'x' indicates the canal was left empty

Region	Tooth	Canal	Status of canal
1	26	Mesiobuccal	10
		Distobuccal	x
		Palatal	15
	27	Mesiobuccal	10
		Distobuccal	x
		Palatal	15
2	36	Mesiobuccal	10
		Mesiolingual	x
		Distal	15
	37	Mesiobuccal	10
		Mesiolingual	x
		Distal	15

All the initial preparation of the bone and tooth material was carried out by one operator (VB).

Imaging

All imaging in the study was performed using a Heliodent MD intraoral X-ray set (Siemens, Bensheim, Germany) operated at 60 kV (constant potential) and 6 mA. The focus to end of the space-defining cylinder was 300 mm. Available exposures ranged from 10 to 2000 ms with 19 intervening settings. Prior to commencing the study, an assessment was made to confirm linearity of tube output against time. Output was measured by placing the end of the space-defining cylinder against the sensitive area of a digital dosemeter model 35065 (Keithley Instruments Inc, Cleveland, OH, USA) and performing exposures at each of the possible exposure times. The mean output of three readings was calculated and plotted against exposure time (Fig. 1). The results confirmed a linear relationship and hence the suitability of the X-ray unit for the study.

Three imaging systems were investigated:

1. 'Insight' dental X-ray film (Kodak, Hemel Hempstead, UK). All films were taken from a single box of size two film (Batch No. 214 4242).

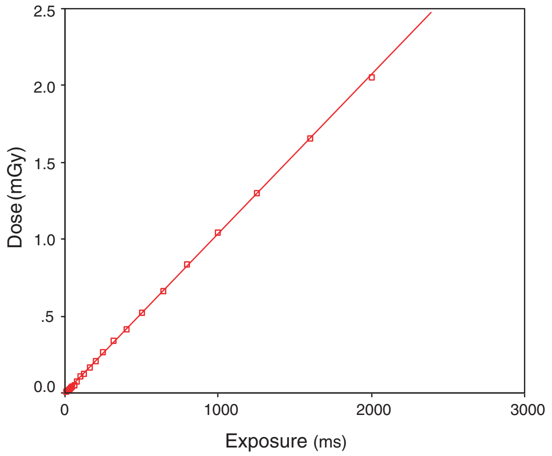

Figure 1 Relationship between radiation dose (mGy) and exposure time (milliseconds) for the X-ray set used in the study.

2. Visualix USB (Dentsply, Gendex Dental Systems, Milan, Italy), used with Vixwin 2000 software, version 1.4 (Dentsply, Gendex Dental Systems). The same size two sensor was used throughout.

3. Digora FMX (Soredex Orion Corporation, Helsinki, Finland). This was used with Digora for Windows software. A single size two imaging plate from a new set of plates was used.

The digital systems were used with a Dell Optiplex GX150 personal computer (Dell Inc., Round Rock, TX, USA) with a Samsung Syncmaster 171 s 17″ flat panel monitor (Samsung, Wynyard, UK), high colour (32 bit) and screen size 1280 × 1084 pixels.

In order to perform radiography, a standardized imaging procedure was devised. Rinn XCP film holders were used as standard, the metal arm being impressed into greenstick composition applied to the occlusal surfaces of the teeth to permit reproducible positioning. A Rinn bite block was attached to the arm for conventional film and a special sensor holder designed for use with the Rinn XCP system was employed for Visualix USB. In the case of Digora, a conventional Rinn bite block was modified to allow use of the imaging plate.

Exposures were made of the maxilla and mandible using each of the three imaging systems at each increment of exposure time. Conventional films were processed in a sensitometrically monitored Dürr AC245L dental X-ray processor (Dürr Dental GmbH & Co., Bietigheim-Bissingen, Germany) in a single processing session. Thus, 21 images were available for each of the three systems. These images were, for each system, randomly numbered and ordered to conceal the exposure times used.

Image quality assessment

Five observers examined the images individually. Two were specialist dental radiologists and three were specialists in endodontics. Film images were viewed on the same viewing box with the help of a ×2 magnifier and with dimmed room lighting. Digital images were viewed direct from the computer monitor screens in a room with the lights turned off. No adjustments to image brightness or contrast were permitted.

Images were scored by the observers according to the visibility of the endodontic files, root canal anatomy, periodontal ligament space, lamina dura and periapical bone detail. One person (VB) spent time with each observer prior to each assessment explaining the scoring system and objective of the assessment. The scoring was carried out following the method described by Borg *et al.* (2000) and originally derived from Vucich (1979), but modified so that the quality assessment was focused upon factors of importance to endodontics and excluding factors such as caries and periodontal disease.

Observers graded each image by allocating a single overall score using the following five point scale:

1. Important structures not visualized.
2. Important structures poorly visualized.
3. Important structures visualized.
4. Important structures adequately visualized.
5. Important structures optimally visualized.

Data analysis

Data were entered on SPSS version 11. Inter-observer agreement for image quality assessment was measured using weighted kappa statistics and the results interpreted using the following definitions (Landis & Koch 1977): 0.01, Poor; 0.01–0.20, Slight; 0.21–0.40, Fair; 0.41–0.60, Moderate; 0.61–0.80, Substantial; 0.81–1.0, Almost perfect.

Image quality scores were considered for each observer individually and also as the mean score for each image. Paired samples *t*-tests were performed to compare the image quality achieved by the three systems.

Results

Inter-observer agreement

The weighted kappa scores for inter-observer comparisons are shown in Table 2. In all cases, agreement was greater than or equal to 0.40. However, in all assessments except those for the Visualix USB and involving Observer 5, agreement was greater than, or equal to, 0.61 (substantial or better).

Image quality and exposure relationships

Image quality scores for the three systems were plotted against $\log_{10}$ exposure time. An example, for Observer 1, Region 1, is shown in Fig. 2. Finally, image quality data from both Regions and from all five observers were averaged and plotted against $\log_{10}$ exposure time (Fig. 3). Table 3 summarizes the key features of Fig. 3. Maximum image quality (4.0) was seen for conventional film and neither digital system achieved this score at any exposure. In both cases, the best mean score was 3.1 (adequate visualization). The two digital systems, however, provided adequate visualization at substantially lower exposure times. The dose reduction over conventional film for maximum quality images with Visualix USB was 20%, but for Digora FMX it was 70%. All three systems gave acceptable (quality score of two or higher) images over a broad range of exposures. Paired samples *i*-tests on the image quality scores (averaged data for both Regions and from all five observers) for the three systems indicated that Digora FMX had a significantly higher mean image quality score than Visualix USB ($P = 0.016$), but that there was no significant difference between the mean image quality score of film and Digora FMX ($P = 0.923$) or film and Visualix USB ($P = 0.353$).

Table 2 Agreement (weighted kappa scores) for image quality assessments of the three imaging systems by the five observers

Compared examiners	Film	Visualix USB	Digora FMX
1 and 2	0.88	0.91	0.84
1 and 3	0.72	0.76	0.62
1 and 4	0.80	0.84	0.63
1 and 5	0.94	0.40	0.71
2 and 3	0.72	0.81	0.69
2 and 4	0.75	0.81	0.69
2 and 5	0.84	0.43	0.82
3 and 4	0.61	0.83	0.84
3 and 5	0.71	0.47	0.73
4 and 5	0.79	0.40	0.73

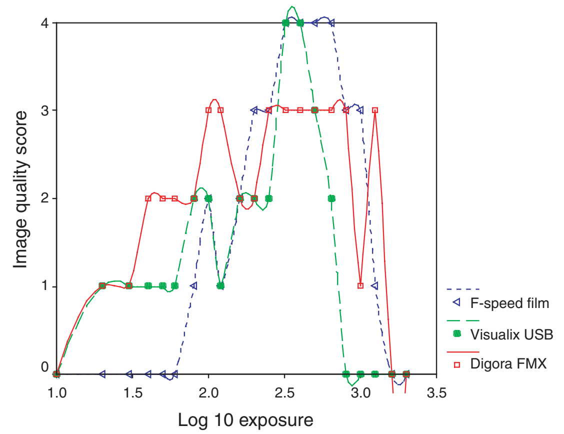

Figure 2 Relationship between exposure time and image quality scores made for the three imaging system by Observer 1 for the maxillary specimen (Region 1).

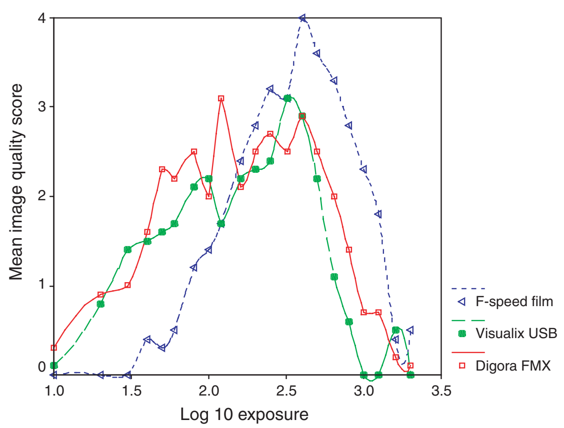

Figure 3 Relationship between exposure time and image quality scores for the three imaging systems (mean scores for Regions 1 and 2 by all five observers).

Discussion

It is very important to minimize radiation dose without compromising optimal image quality. This forms just part of the constant pursuit of high quality dental care. The aim of this study was to measure and compare the relationships between image quality (in an endodontic context) and X-ray exposure for the three principal types of intraoral imaging system. Such a study should be considered as providing the important information when evaluating the performance of imaging systems in the context of changing X-ray equipment. Efficacy must be measured at several different levels (Fryback &

Table 3 Summary of image quality characteristics for the three imaging systems. 'Acceptable' image quality relates to a mean quality score of two or higher

Imaging system	Maximum quality score	Exposure for maximum image quality (ms)	Range of exposures for 'acceptable' image quality (ms)
Film	4	400	160–1000
Visualix USB	3.1	320	80–500
Digora FMX	3.1	120	50–640

Thornbury 1991), including (amongst others) technical objective measurements and specific clinical tasks. Nevertheless, the assessment described here provides a useful 'overall' assessment of quality that comes as close as is practical to mimicking the clinical situation and the 'accept/reject' judgement of radiographic images performed daily by clinicians.

The main focus of this investigation was to compare the image quality achieved for the three imaging systems. A secondary interest was to compare the ranges of exposure over which acceptable quality could be obtained. Statistical comparison of the mean image quality scores using paired samples *t*-tests suggested that Digora FMX was 'better' than Visualix USB, with no significant difference between film and the two digital systems. This method of comparison, while statistically correct, needs to be interpreted with Fig. 3 clearly in mind, as it does not reveal the marked shape difference in the curves for each imaging system and the better maximum image quality achieved by film. Certainly, Borg *et al.* (2000) did not make a statistical analysis of the data in their study but relied upon simple visual interpretation of image quality/radiation exposure curves.

Unlike conventional film and PSP, CCD did not give any readable images at very high exposures. This is because of the phenomenon of saturation of the CCD, and is in agreement with previous studies (Borg & Grondahl 1996, Borg *et al.* 2000). This and other obvious differences in the system meant that the observers could not be made 'blind' to the system used, so some bias might have crept in. It is noted that Observer 5 had results for CCD at marked variance to the other observers that might reflect some pre-existing bias. An alternative approach would have been to digitize the conventional films and export the digital images to one common viewing environment, as was done by Berkhout *et al.* (2004). This effectively 'blinds' the observer to the identity of the imaging systems. In the present study, it was decided to use the images in their normal format as it was judged that this would give a more realistic assessment, in particular of conventional film. Both approaches, ours and that of Berkhout *et al.* (2004) have good and bad points. For the digital systems, observers were not permitted to adjust monitor contrast or brightness in any way. Neither were they allowed to change the light intensity of the viewing box for film images. Image quality scores might have improved if adjustments had been allowed, but a decision was taken that favoured using an objective, reproducible method rather than allowing an uncontrolled approach. Future research might usefully extend this work by examining the effects on image quality of giving observers 'free rein' to alter images to subjectively perceived optimal quality.

The results showed that the phosphor plate system had the lowest exposure for the maximum image quality when compared with Visualix USB and film. When comparing the relative dose for maximum image quality with the help of Fig. 3 and Table 3, Digora FMX gave a 70% dose reduction and Visualix USB only a 20% dose reduction when compared with film. However, such precise statements must be interpreted with caution because this refers to maximum image quality only. Table 3 also shows that wide exposure ranges can give 'acceptable image quality'. Using the minimum dose compatible with acceptable image quality for all three systems, the dose reduction over conventional film achievable by Visualix USB improves to 50%. The range of exposures for acceptable image quality is such, however, that it is possible to have a situation in which film could be used clinically at much lower doses than either digital system. It is important that the clinician using any imaging system is aware of this apparent paradox.

Previous similar studies (Borg & Grondahl 1996, Lim *et al.* 1996, Borg *et al.* 2000, Kitagawa *et al.* 2000, Berkhout *et al.* 2004) cannot be exactly related to this one because the combinations of imaging systems used were different. Nonetheless, a few similarities can be observed. The wide exposure latitude of phosphor plate systems and the 'saturation' of CCD systems at higher exposures are common features. Nonetheless, the present study is the first to include Kodak 'Insight' (F-speed) film in a direct comparison with digital systems in this type of study. The good performance of conventional film is a reassurance to those clinicians who have remained loyal to the traditional form of imaging. For the CCD system, the exposure latitude was wider than expected, certainly in comparison with the

results of Borg & Grondahl (1996), although they used a different CCD system. This probably reflects improvements in system function over the intervening years.

Like Borg *et al.* (2000) and Berkhout *et al.* (2004) dried mandibles were used in this study. The reason for doing this rather than concentrating on patients (clinical study) was that it was ethically difficult to expose patients to such repeated radiation doses. It is also likely that control of radiographic positioning is more consistent and reproducible for laboratory specimens than for the *in vivo* situation. Unlike Borg *et al.* (2000), a maxillary specimen was used in addition to the mandibular material, as this was considered to provide extra information and not merely duplicate the mandibular findings. The option of using cadaver material, such as was done by Kitagawa *et al.* (2000), was not a practical option.

Molar regions of the maxillary and mandibular regions were considered suitable for the study as these presented teeth that were not grossly decayed and had proximal contacts. Apart from this pragmatic aspect of selection of material, it was felt appropriate to use posterior teeth as the more complex root and pulp anatomy would represent a better test of the imaging systems. Certainly, one previous study (Shearer *et al.* 2001) has shown that digital X-ray systems preformed less well than conventional film for imaging root canals. Extracted teeth in blocks were not selected because of the focus on the periodontal ligament space, lamina dura and periapical bone characterization as well as the file visibility and root canal anatomy. Shearer *et al.* (2001) used extracted teeth on blocks of soft tissue equivalent material and a section of mandible was placed over the block prior to imaging. However, their technique can still be criticized in that it was a more 'artificial' arrangement than that used in the current study, where the presence of bone trabeculae in the bony specimens added more realistic 'noise' to the image, more closely mimicking the *in vivo* situation.

Green stick compound was selected as a soft tissue analogue to mimic real life because it was easily mouldable, sticky and could be shaped to simulate the soft tissue thickness of the face. The thickness was set to approximately 5 mm because it was best found to mimic facial thickness at this measurement. Borg *et al.* (2000) in their study placed the mandibular sections behind a polymethacrylate cylinder with 2 mm thick walls and a 20 mm hollow space. The space was filled with water to simulate the soft tissues. In terms of X-ray attenuation, water is very similar to most soft tissues. Green stick composition is not similar in X-ray attenuation and it had to be compensated appropriately by adjusting thickness. However, despite this disadvantage it was judged that the malleability of the material was satisfactory.

Small endodontic files were used in the teeth because the canals were narrow, but such fine instruments are also better for testing the imaging system as previous work has shown that small files (size 10) may be less clear or incompletely seen on digital images (Velders *et al.* 1996, Friedlander *et al.* 2002, Lozano *et al.* 2002). It was pointless to test a system using a large file as ample research evidence suggests that large files present no challenge to any imaging system.

It was decided to use 70 or 60 kV because that is the exposure range used most frequently in Europe and in most of the other parts of the world. Therefore, the results of the study can be applied widely. In the US, however, a higher kilovoltage range is used. In a study conducted by Nishikawa *et al.* (1999) to compare the dependency of dose response of five CCD-based digital intraoral radiographic systems on tube voltage, it was found that in the newer systems using a rare earth intensifying screen as a scintillator, the sensitivity increases with increase in tube voltage. This work indicates that it is important to remember that the results of the current study may not be valid where higher kilovoltages are customarily used, such as in the USA.

'F'-speed film was used in this study and it was found from the review of literature that none of the previous similar studies used this type of film. Film speed is in part determined by grain size, with bigger grains giving a faster film speed. Grain size is an important factor in resolution. Thus image detail may be influenced and the results of previous studies may not be entirely applicable to 'F'-speed film. This emphasizes the importance of continuing research in this field to avoid information based on outdated or obsolete imaging systems influencing current choices of equipment.

All of the intraoral imaging systems (film, CCD and PSP) offer the choice of image receptor size. Size two receptors were used throughout the study because using a smaller film or sensor for any one system may have put that system at a disadvantage or advantage in terms of image quality assessment. As no Digora plate-compatible Rinn bite block is manufactured, it was necessary to alter the film bite blocks to accommodate the greater thickness of the plate.

All observers were allowed to use the magnification viewer while viewing films and when they were

viewing the images on the CCD and PSP they were not allowed to alter the brightness or contrast. These rigid constraints on the observers provided greater experimental control but are somewhat detached from real clinical practice. Therefore, future work might explore the impact of permitting alterations in viewing conditions. It is of some reassurance that Cederberg *et al*. (1999) in their study on the influence of the digital image display monitor on observer performance found that the observer performance is independent of the visual characteristics of the display monitor.

It is important with any laboratory-based research of this kind to put the results and their implications into an everyday clinical context. One important implication is for the endodontist who is selecting new equipment for imaging. Choice of 'hardware' in dentistry is a matter of balancing cost and benefit. Film is cheap and also gives good quality images. With digital systems, factors such as exposure latitude should be taken into account. A perceived advantage of the wide latitude of phosphor plate systems is that it allows the dentist to cope with a bad choice of exposure: the systems tolerate 'sloppy' practice. However, while the latitude will allow a low dose deliberately to be selected in more careful hands, it might also permit a high dose to be used (Berkhout *et al.* 2004). Thus, a careless operator might think he or she is giving lower doses to patients while in truth giving higher doses than are reasonably achievable.

Conclusions

F-speed film gave better image quality than was achieved by either digital X-ray system. All three systems (film, Digora-FMX and Visualix USB) gave acceptable image quality over some part of the exposure range, with film having the widest latitude and Visualix USB the narrowest. In terms of potential dose reduction, Digora FMX offered the lowest dose for its maximum image quality. As film remains a much cheaper option for clinicians, each dentist should carefully balance the perceived benefits of the new technologies against the cost and complexity.

Acknowledgements

We thank the help of the radiographers who accommodated the research and advised on technical matters, in particular Mrs Angela Carson, Superintendent Radiographer.

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